Improved Measurement, Monitoring, and Mitigation of N_2O Emissions and Related N Losses from Intensively Fertilized Agro-ecosystems

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1. **Methods development**
2. **Plot studies: Fertilizer mgmt impacts on N_2O emissions**
3. **Extension & education**

Anthropogenic N_2O Sources

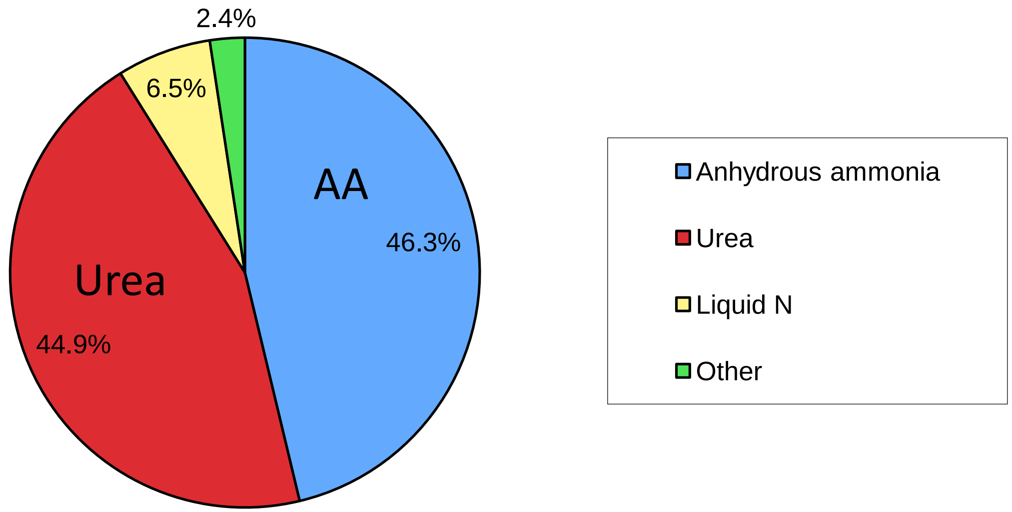
Fertilizer application:	40%
Manure application & mgmt:	40%
Biomass burning :	7%
Industrial:	14%

Davidson, 2009; Mosier et al.,1998

- Some studies large effects of particular N mgmt practices, but there's been very few of them.
    - Chemical source
    - Application method, placement, timing
    - Use of specialty fertilizer products
- Other than fertilizer rate, practices are not being considered in emissions assessments
- Need for replication in different soils and cropping systems

Survey of N Management Practices in Minnesota (Bierman et al., 2011)

Urea and Anhydrous Ammonia dominant forms - together account for > 90% of total



- Only 1 cropping system in MN has compared AA and Urea (Venterea et al., 2005; 2010)
- Only 1 other cropping system in U.S. (Thornton et al., 1996)

Objectives

Plot-scale studies

1. **Compare N_2O emissions under different N fertilizer mgmt practices**

a. **Different chemical sources: Anhydrous ammonia (AA) vs. Urea**
b. **Placement effects: depth of AA injection**
c. **Controlled release fertilizers (CRFs): Polymer-coated Urea and Urea + inhibitors**

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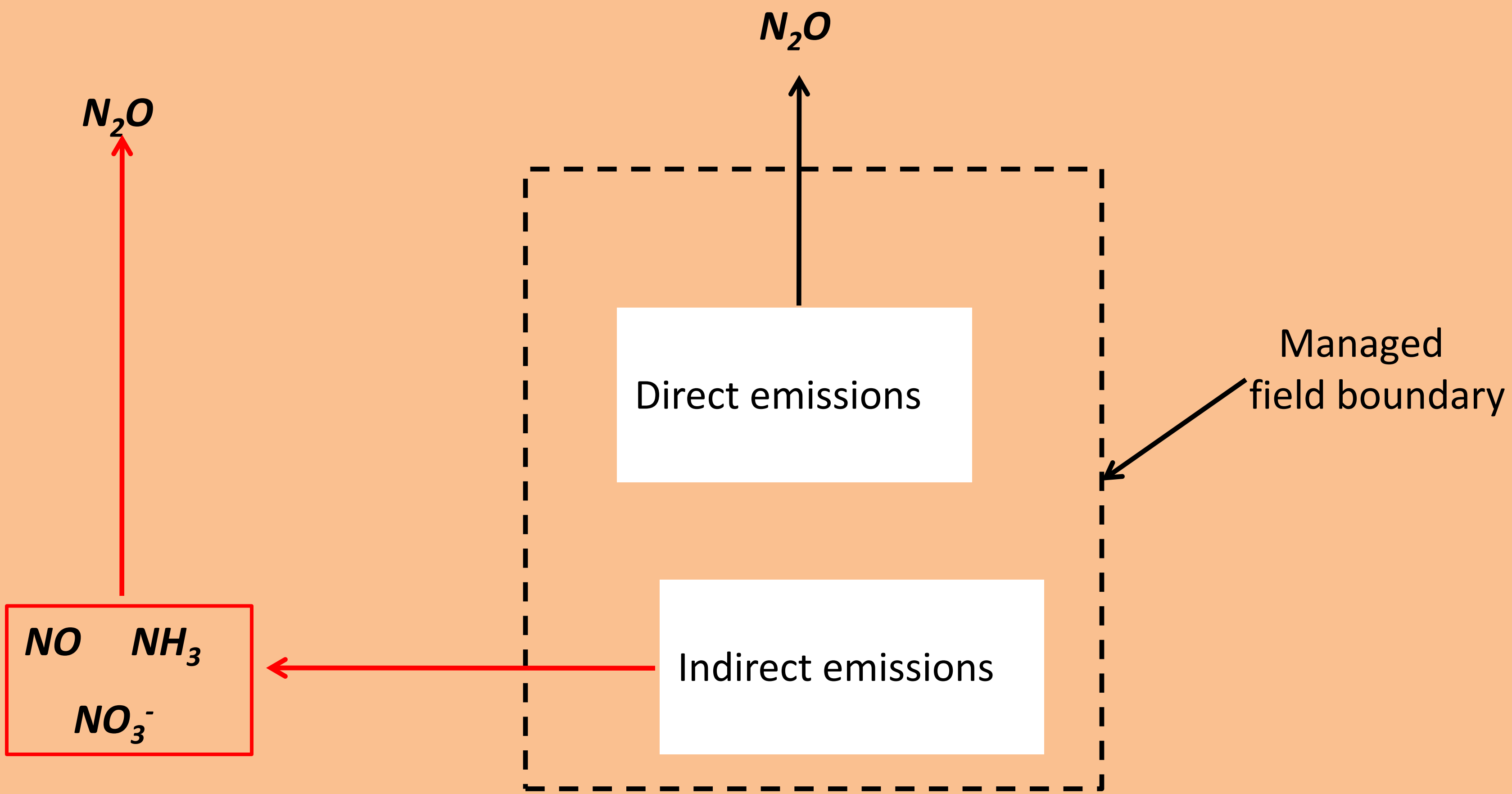
2. **Account for both direct & indirect N_2O emissions during the growing season**

a. Direct soil-to-atmosphere N_2O emissions using chambers
b. Indirect emissions: NO and NH_3 emissions using chambers
c. Indirect emissions: NO_3^- fluxes using lysimeters or sampling tile-drainage water

Direct and Indirect N_2O Emissions



1. **Measure direct emissions and emissions of other N forms**
2. **Use published emissions factors for off-site conversion of other forms to N_2O**
3. **Evaluate management effects on total direct + indirect emissions**

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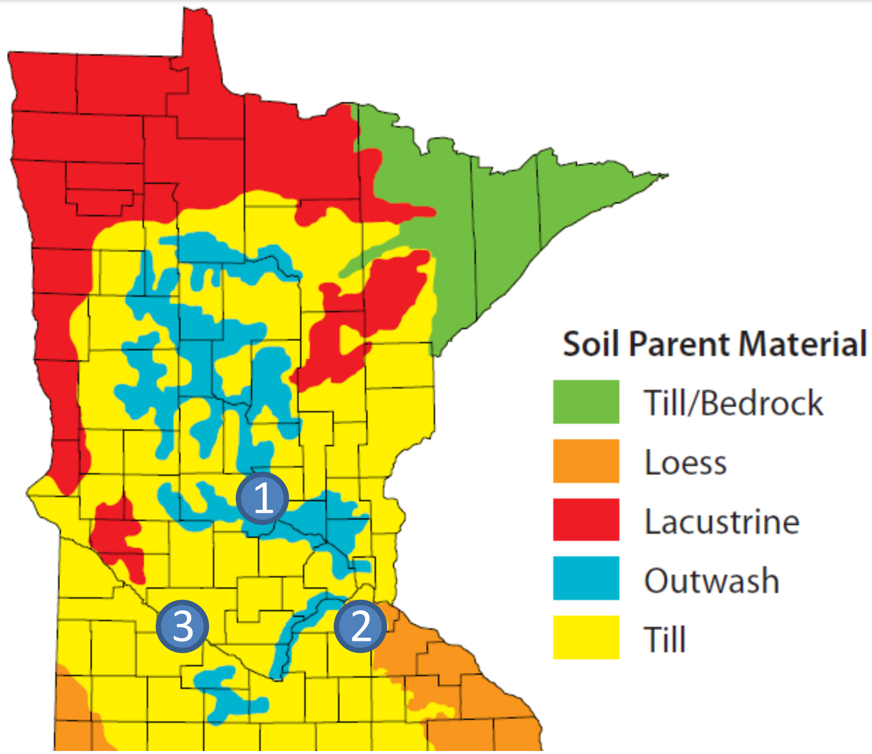
3. Evaluate basic agronomic performance:

a. Grain yields
b. Crop N uptake and nitrogen use efficiency (NUE)

Plot-Study Sites

Location	Parent material	Texture	Soil C	pH	Crops	Drainage	Interacting Factors
1. Becker	Outwash	Loamy sand	1.0%	5.0	Corn Potato	Natural	Irrigation mgmt
2. Rosemount	Loess	Silt loam	2.5%	5.5	Corn/ Soybean	Natural	Tillage mgmt
3. Lamberton	Till	Loam	5.0%	6.5	Corn	Tile	Drainage mgmt

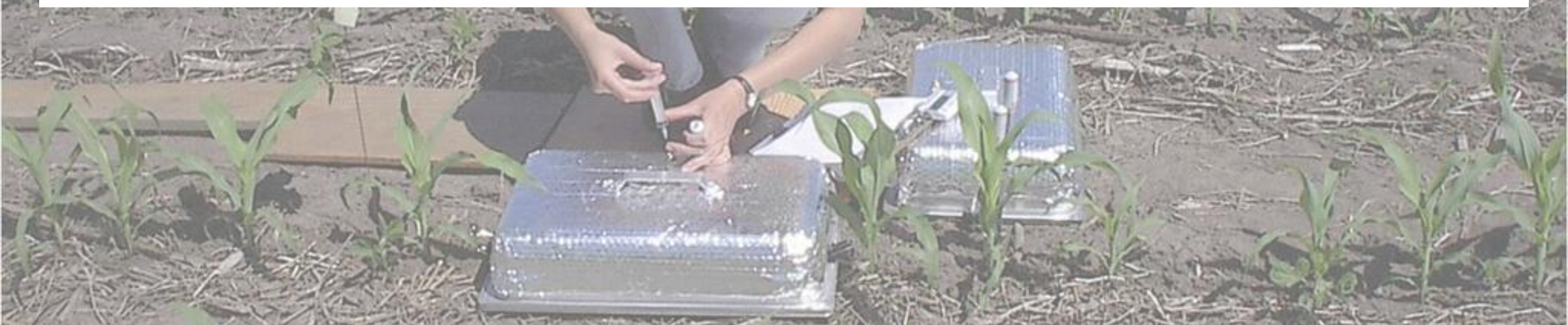


Chambers

N_2O: Chamber sampling by syringe with lab analysis by GC / ECD

NO: In situe, real-time gas analysis using flow-thru chemiliminescent analyzer

NH_3: Method development stage



Pro:

- Plot-scale studies & treatment comparisons
- Inexpensive

Con:

- Limited spatial and temporal coverage
- Suppresses flux

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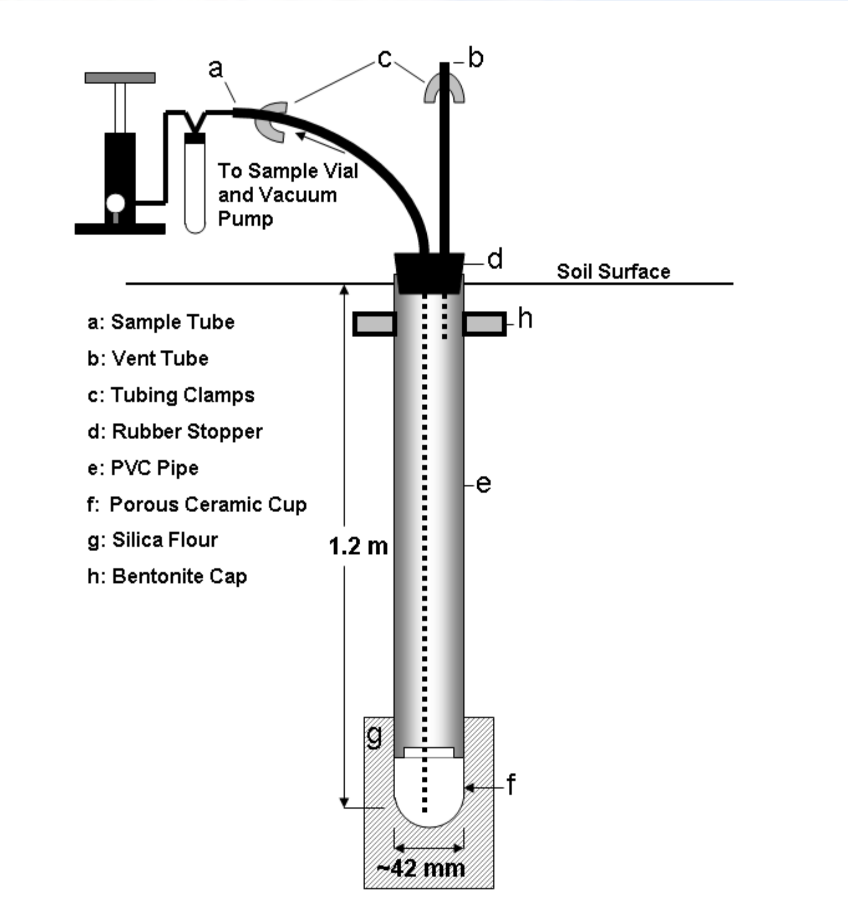
Method to correct for flux-suppression (Venterea. JEQ. 2010)

In-situ, real-time flow-thru gas analysis using laser photoacoustic spectroscopy, (Nitrolux –S Pranalytica)
So far, measured fluxes negligible (< 1 % of applied N fertilizer) in acidic soils
No treatment differences; Method cross-comparison before reporting results

Automated chambers

- Semi-continuous analysis of N_2O and CH_4 fluxes by GC
- One full season completed at Site 2

Porous cup lysimeters



- Sampling of soil-water from below root zone for determining nitrate concentration.
- ET modeling and water balance modeling to estimate nitrate flux.

Becker Site

- Corn cropping system in loamy sand

Two experiments

RCB with n=4 replicates per treatment
Minimum two growing seasons

<u>1. Controlled release versus conventional urea</u>

1. Conventional urea
2. Urea + DCD + NBPT (SuperU)
3. Polymer-coated urea (ESN)
4. Zero-N control

3 years of field data
Irrigated corn
Dryland corn
No effects of N mgmt on N_2O emissions

<u>2. Conventional source and placement effects</u>

1. Urea : broadcast & incorporated
2. AA: injected conventional depth (~ 20 cm)
3. AA: injected at shallow depth (~ 10 cm)
4. Zero-N control

Irrigated corn
2009, 2010

Anhydrous Ammonia Placement Effects

Conventional “Deep” Applicator

New “Shallow/Fast” Applicator

JOHN DEERE

<u>Conventional AA Injection</u>

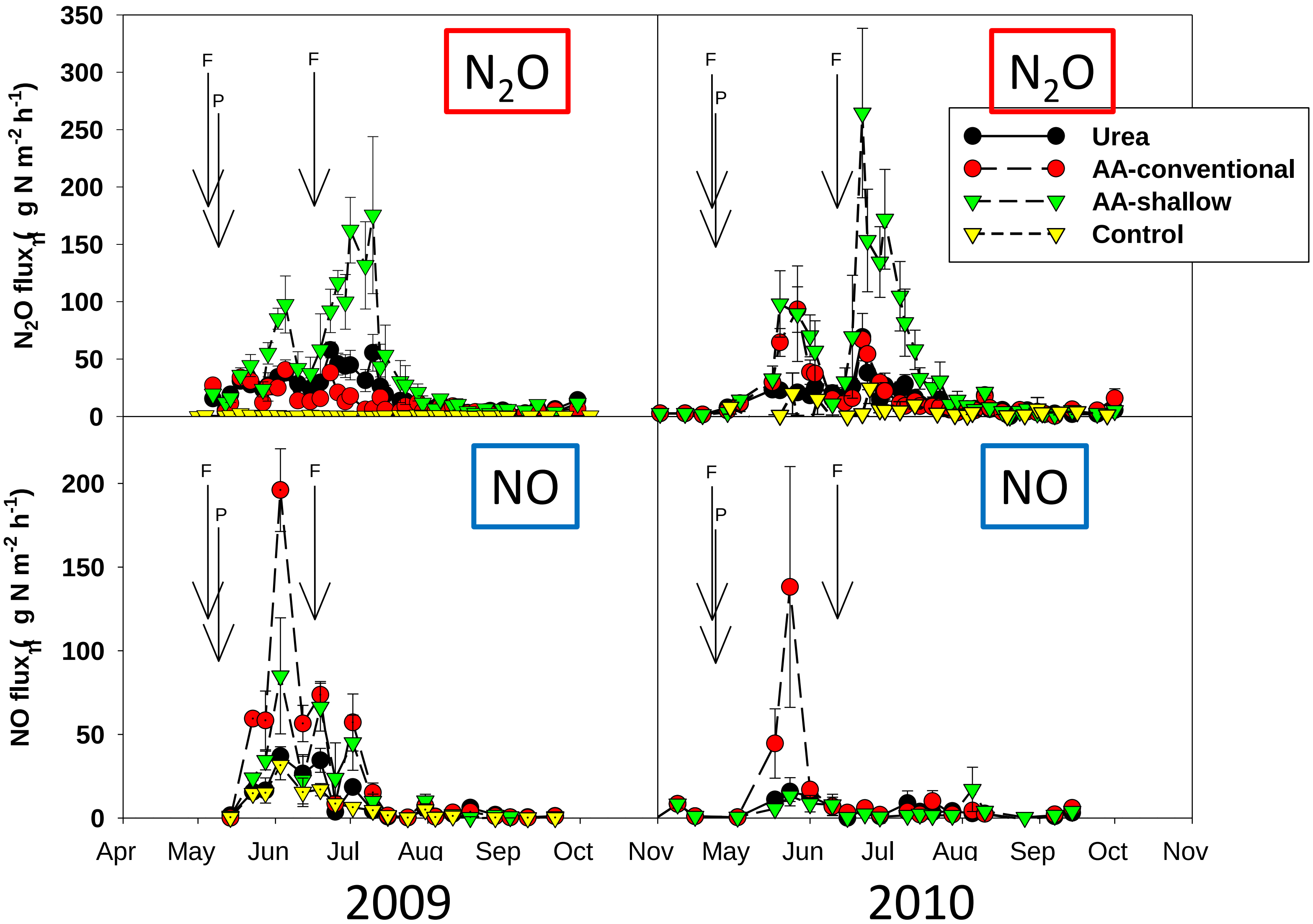
- Slow tractor speed with high fuel use
- 20-cm deep band

<u>Shallow AA injection</u>

- Faster speed
- Less fuel use
- 10-cm deep band
- Improved soil closure implements

Hypothesis: Decreased direct N_2O emissions with shallower AA placement (Breitenbeck & Bremner, 1986)

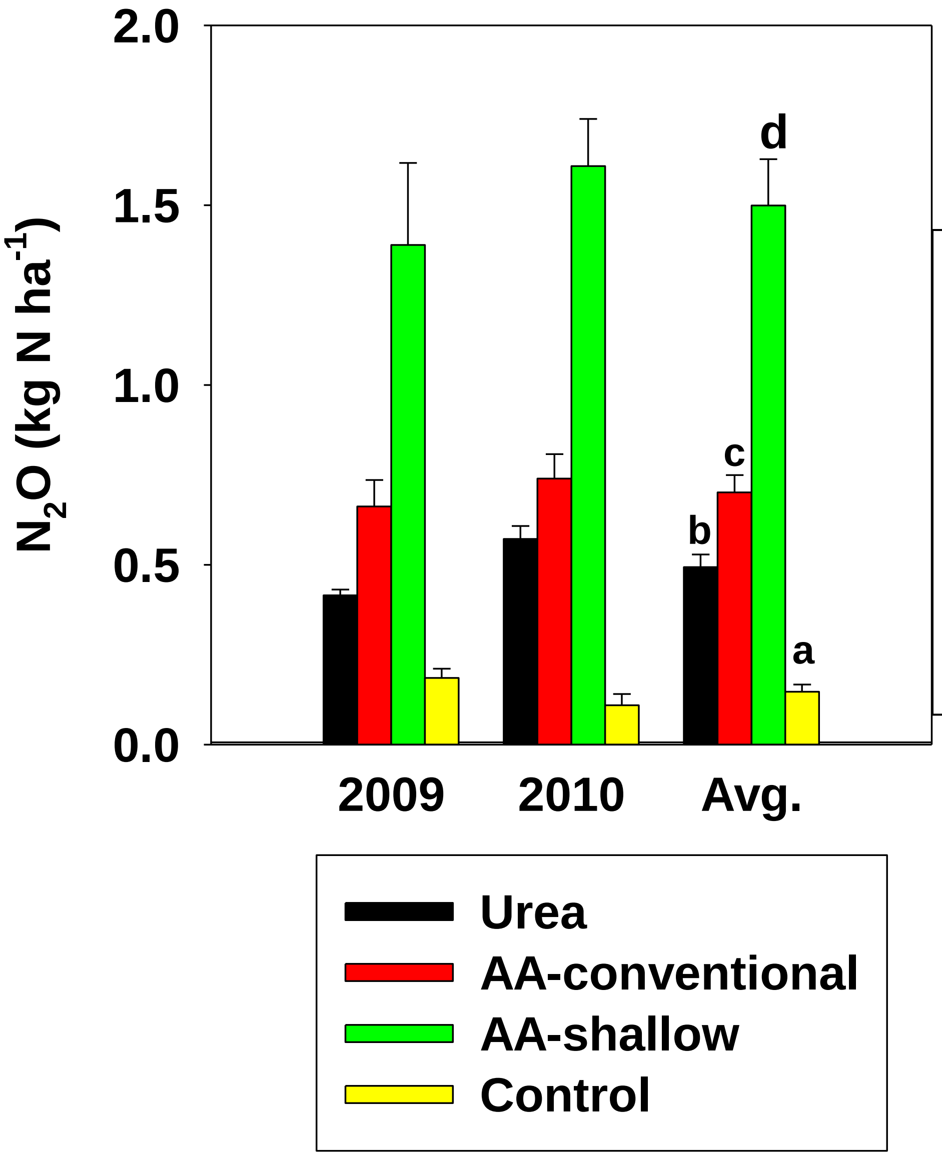
Becker Daily N_2O and NO Fluxes 2009 - 2010



Two split applications of 90 kg N ha^{-1}

Becker Growing Season Fluxes 2009 - 2010

N_2O



Significant differences

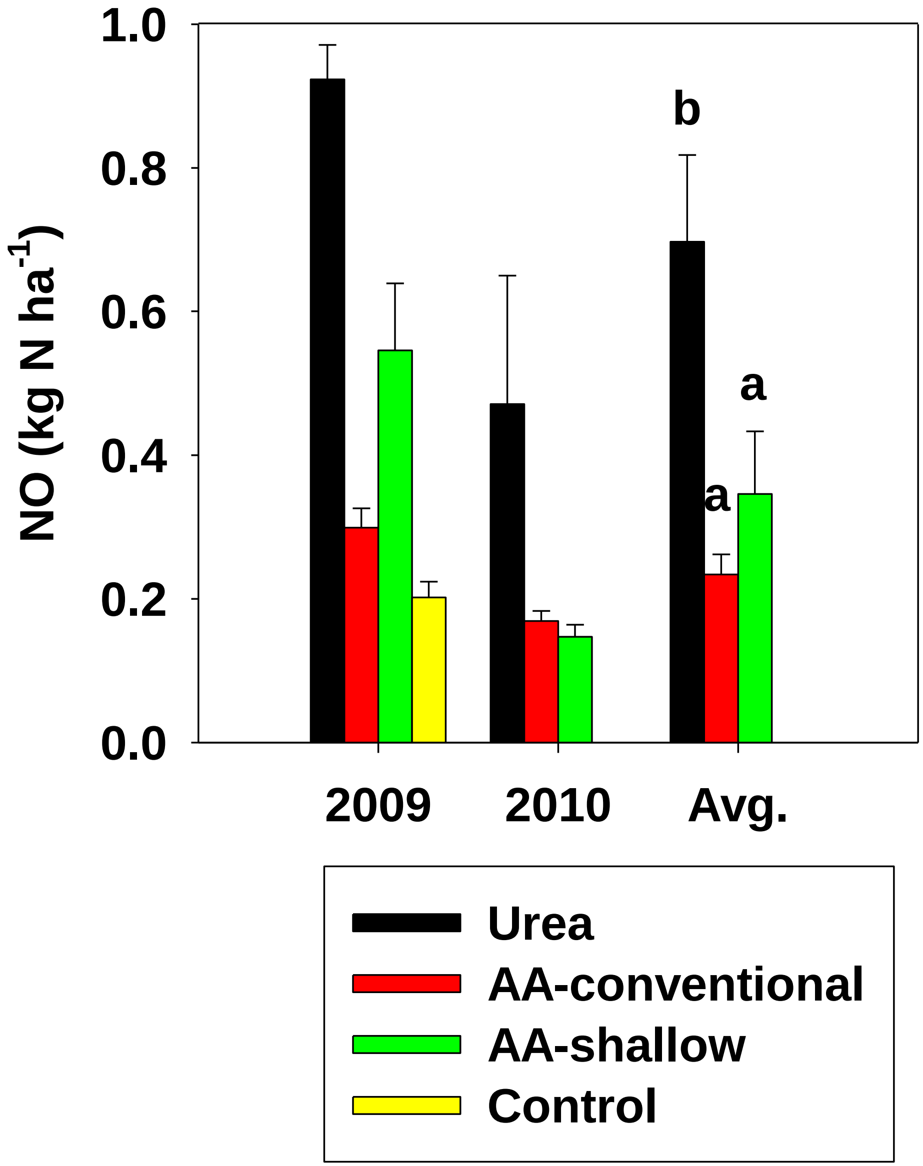
1. AA-shallow > AA-conv
   AA-shallow > Urea

2. AA-conv > Urea

3. Control < Fertilized

Becker Growing Season Fluxes 2009 - 2010

NO



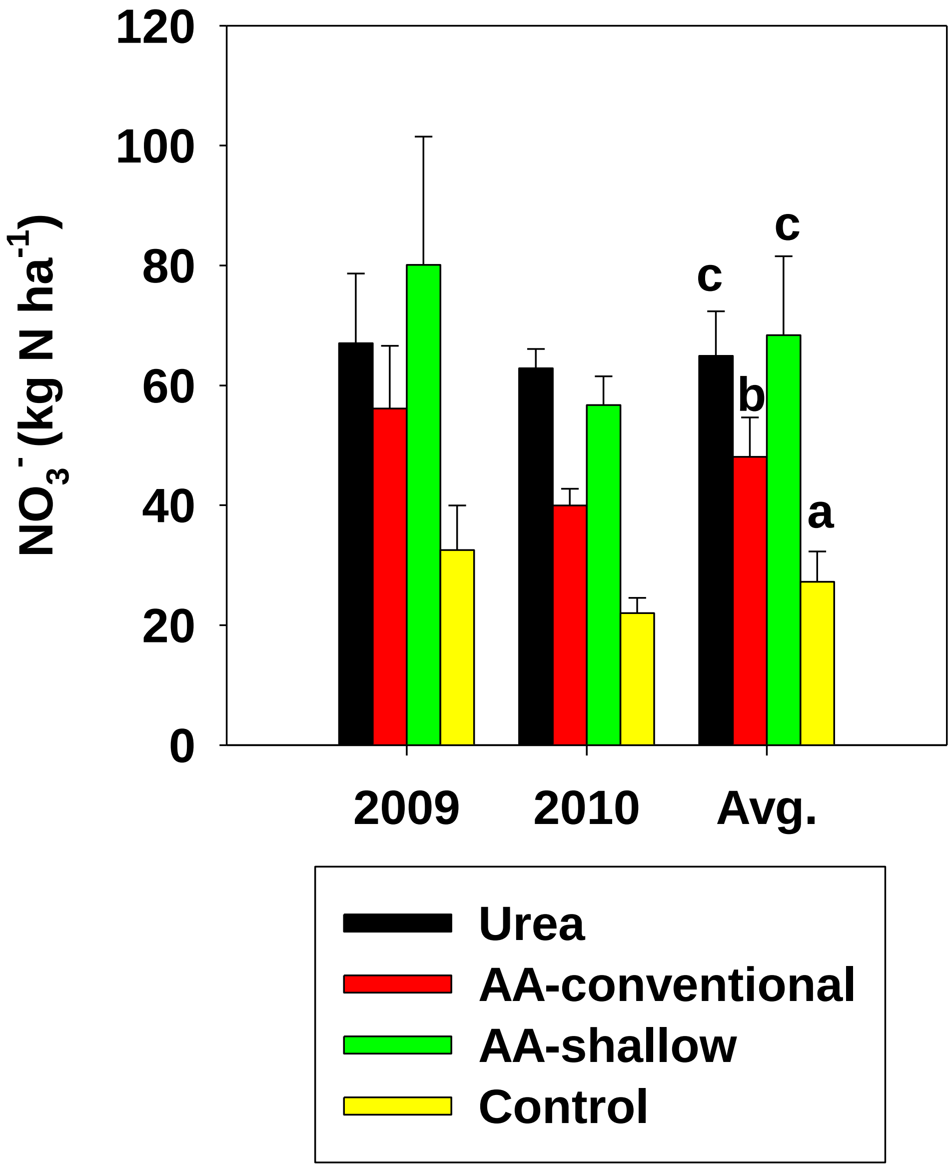
Different pattern of significant differences

Urea > AA-conv

Urea > AA-shallow

Becker Growing Season Fluxes 2009 - 2010

NO_3^-



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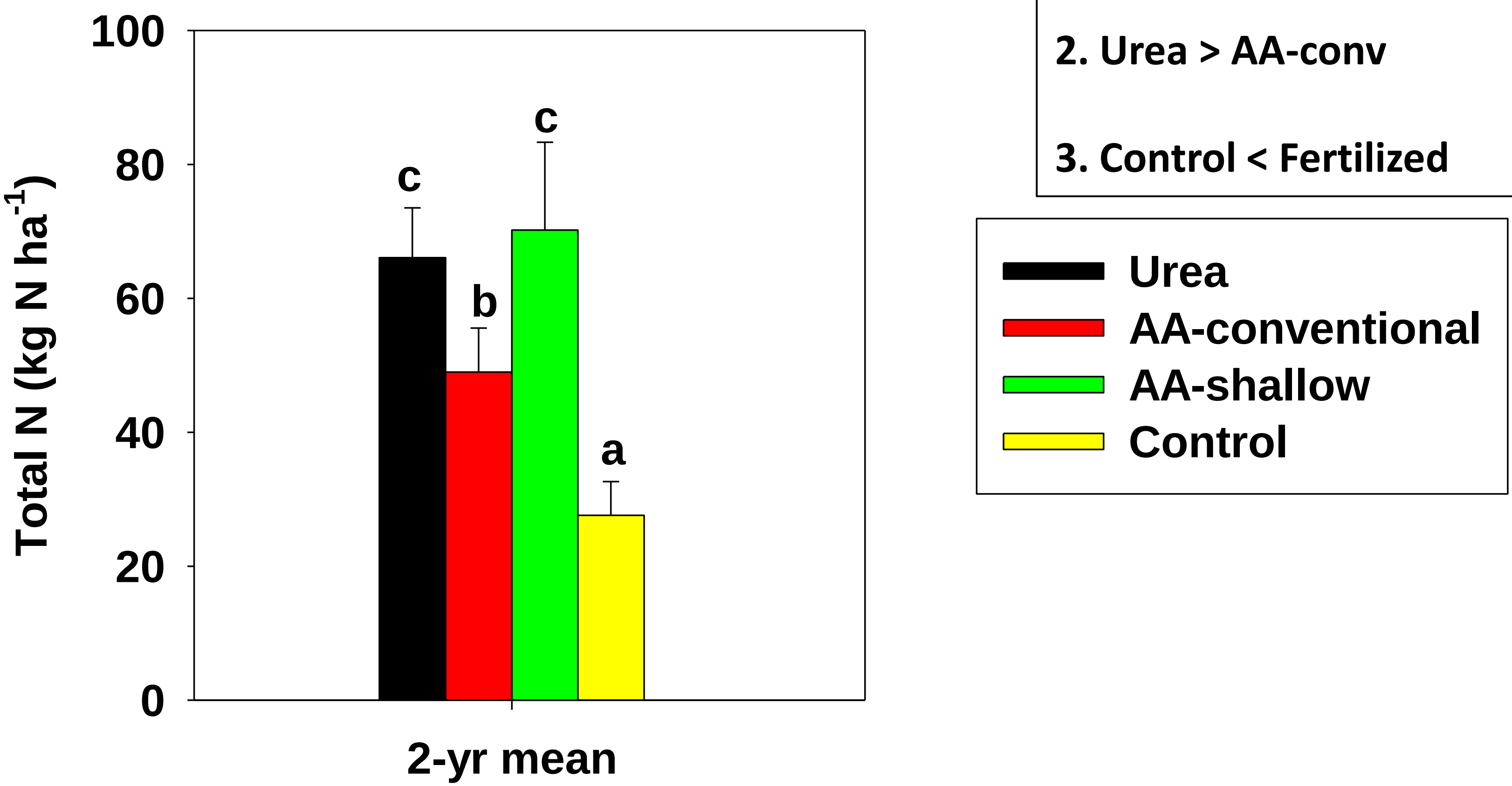
Becker Growing Season Fluxes 2009 - 2010

Aggregated as total N losses = (N_2O + NO + NO_3^-)-N

NO_3^- = 98% of total N losses
N_2O = 0.5% to 2%
NO = < 1%



Significant differences

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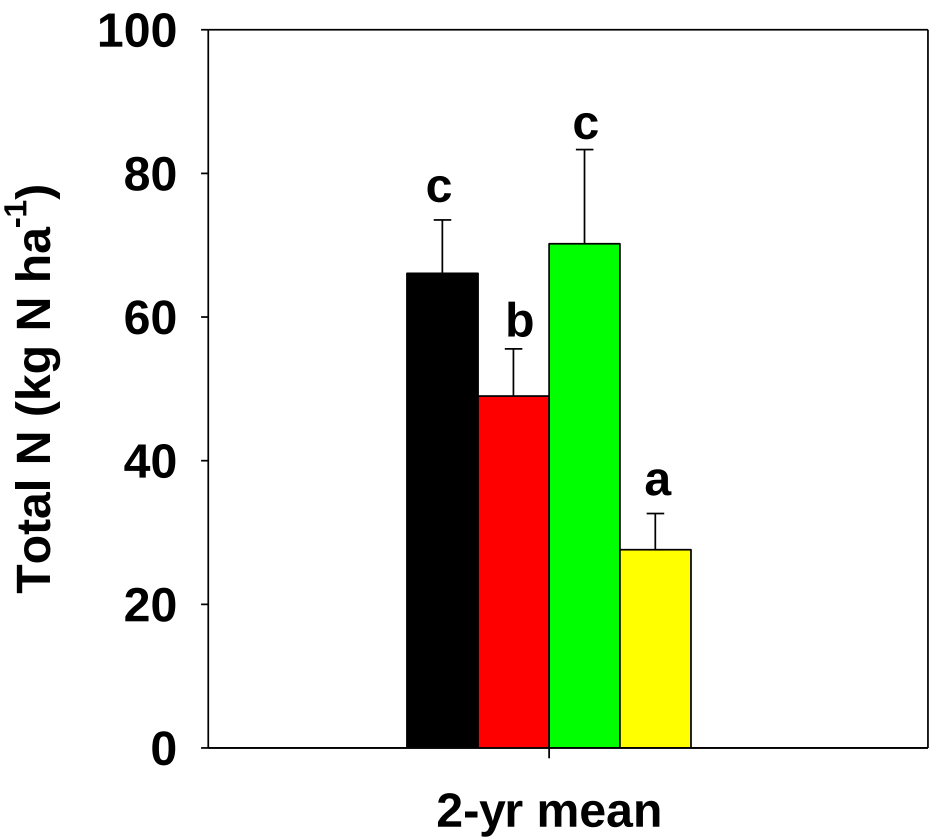
Becker Growing Season Fluxes 2009 - 2010

Aggregated as total N losses = $(N_2O + NO + NO_3^-)$-N

NO_3^- = 30 to 60% of fertilizer N input
N_2O = 0.2% to 0.8%
NO = < 0.3%



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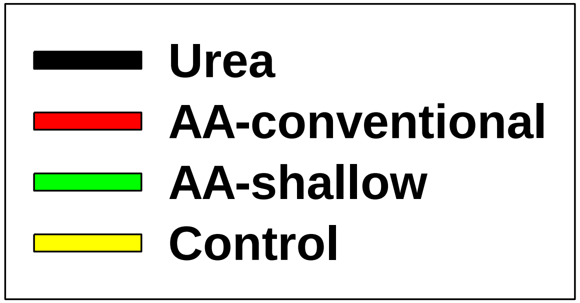


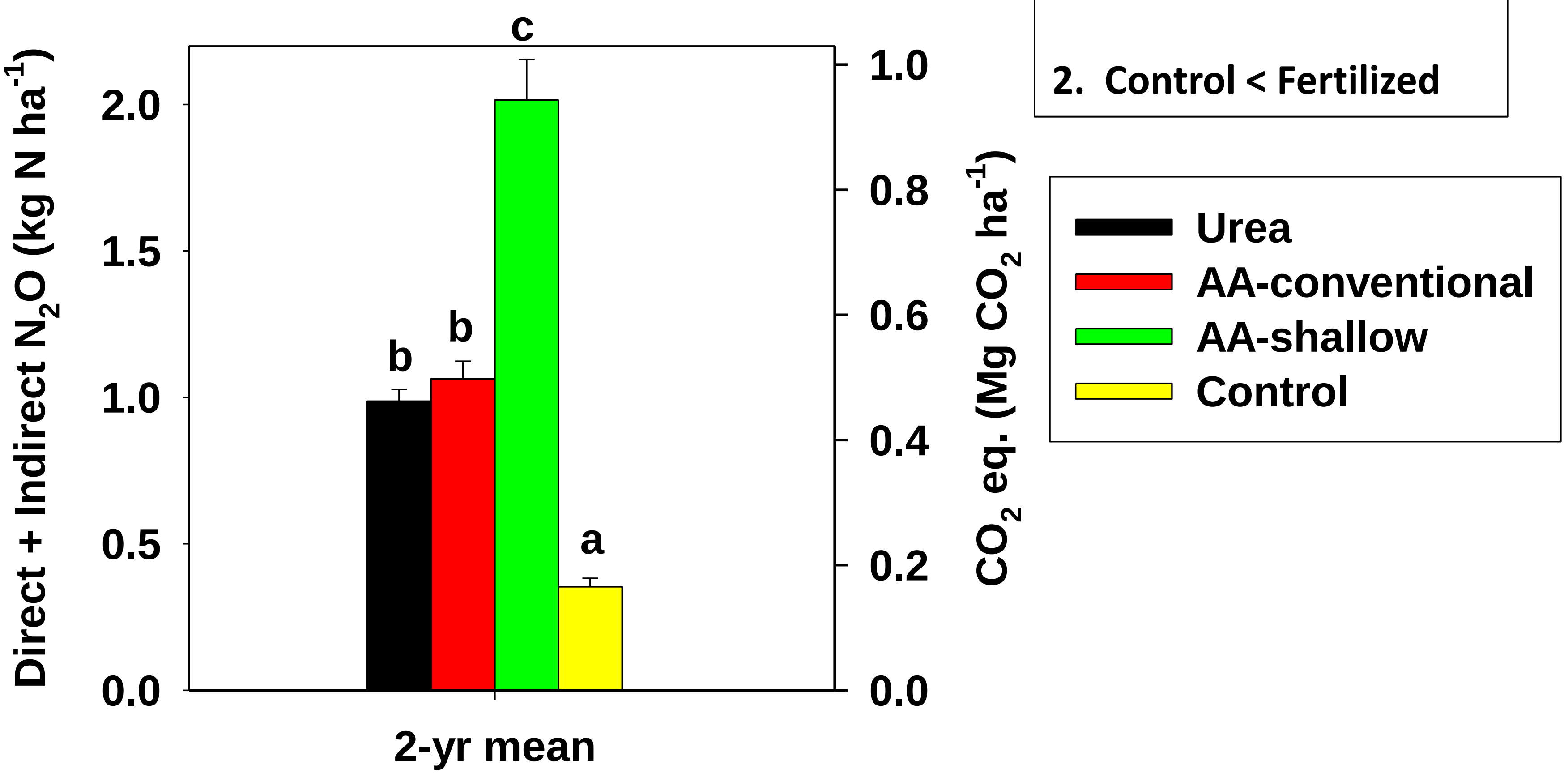
Becker Growing Season Fluxes 2009 - 2010

Aggregated as total N_2O = (N_2O) + (NO X EF_4) + (NO_3^- x EF_5)
(direct) + (indirect)

NO_3^- = 26 to 58% of total CO_2 eq
N_2O = 42 to 74% of total CO_2 eq
NO = < 1%

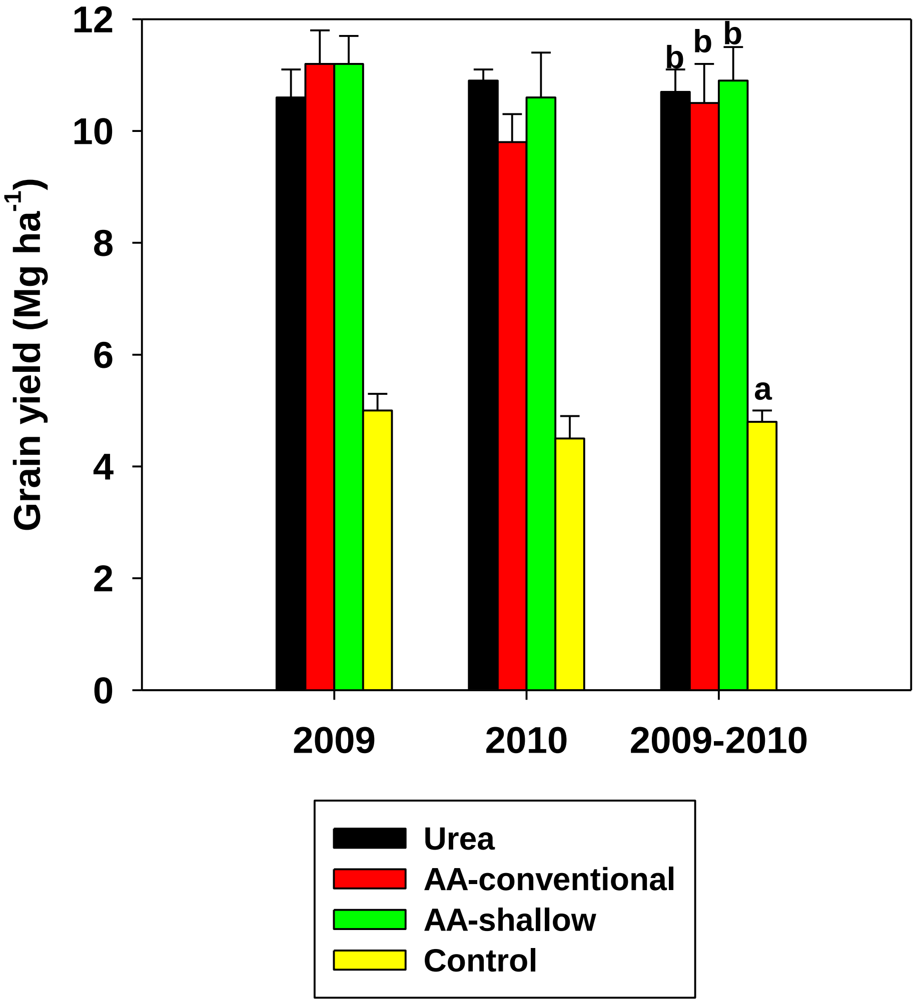
Significant differences

1. **AA-shallow > AA-conv**
   AA-shallow > Urea
2. **Control < Fertilized**



Becker Agronomic Data 2009 - 2010

Grain yields



Significant differences

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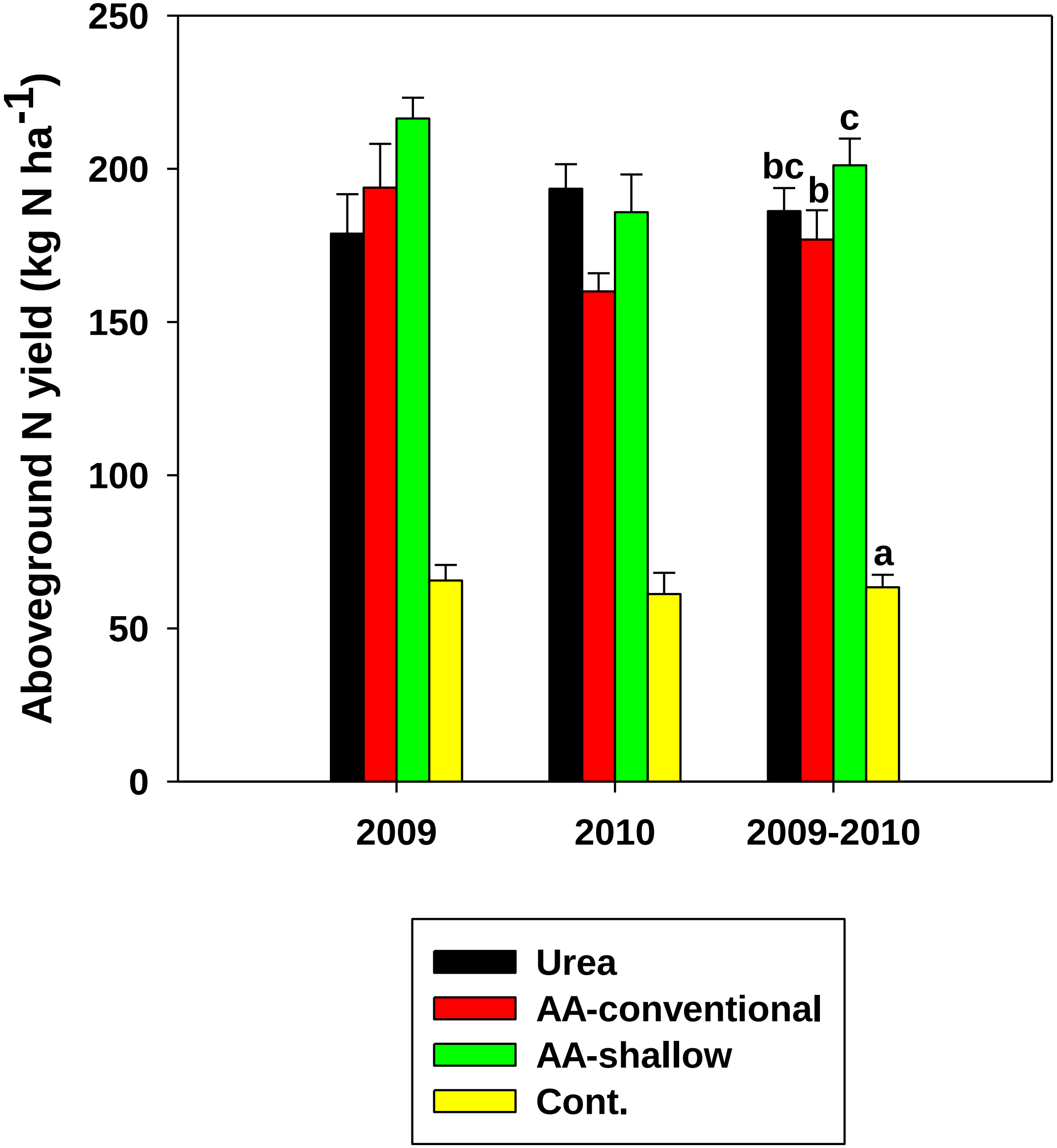
Becker Agronomic Data 2009 - 2010

Above-ground N yield



Significant differences

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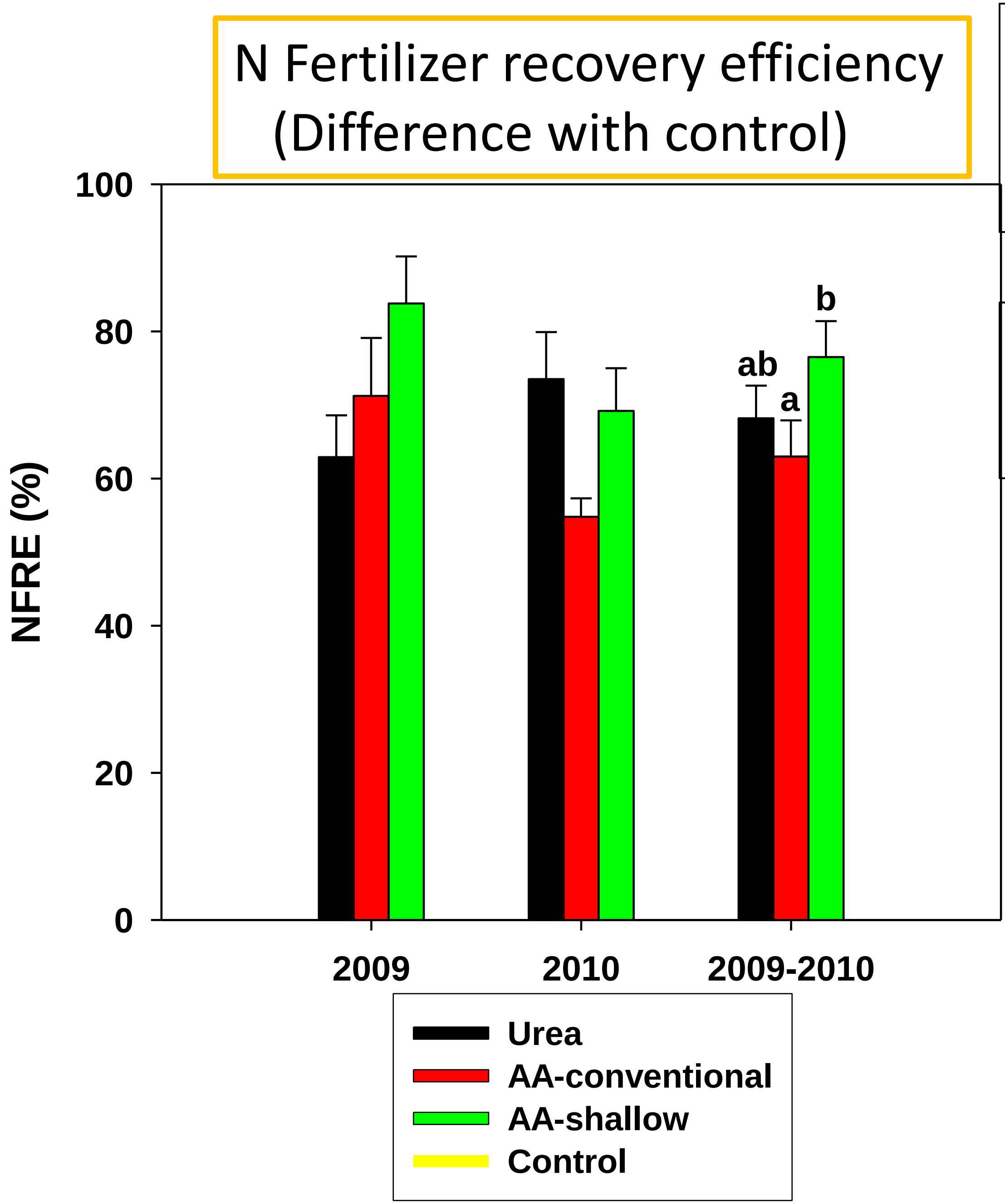
Becker Agronomic Data 2009 - 2010



Unexpected:
Treatment with greatest N losses and total N_2O emissions had best NUE

Significant differences

1. AA-shallow > AA-conv

Mechanisms & Explanations

I. Broadcast Urea versus Conventional AA injection depth

1. Greater direct N_2O emissions with AA
   Concentrated ammonium band that's generated with AA
   → Microbial toxicity effects AA on nitrifying bacteria
   → Nitrite accumulation & high N_2O production under aerobic conditions

2. Greater Nitrate leaching emissions with Urea
   → Slower nitrification and nitrate production with AA

3. Greater NO emissions with Urea
   High reactivity of NO under aerobic conditions
   Shallower placement of Urea compared with AA
   → Less NO consumption in soil prior to reaching soil surface

Mechanisms & Explanations

II. Conventional AA versus Shallow AA injection depth ??

Greater direct N_2O emissions and greater nitrate leaching with shallow AA

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AA injection → Raises pH $NH_3 + H^+$ → Solubilizes SOM Releases DOC, N

- → More N and C released from SOM in shallow treatment due to greater SOM content at 10 cm compared to 20 cm depth (50% greater)
- → Greater release of N and C increased N_2O production and nitrate leaching and also supplied more crop-available N, higher apparent NUE
- → More study needed. Repeating field experiments at two other sites.

Conclusions & Implications

1. More evidence that AA results in greater direct N_2O emissions than urea

- Second soil type to show this in MN, study in third site underway
- Regional and National implications:

  AA = 35% of total N consumption in US in 2008

  Urea = 23%

Complete shift from AA to urea: substantial reduction in direct emissions

Conclusions & Implications

2. Direct N_2O emissions don't tell complete story:

Considering indirect N_2O emissions altered overall treatment effect on total emissions

→ Lower nitrate leaching compensated for greater direct emissions in AA-conv

→ AA-conv had the same total emissions as Urea treatment

Knowledge of both direct and indirect emissions are important

- Logistically challenging to measure all forms of N loss in replicated study
- Estimates of off-site conversion factors highly uncertain

  95% CI of IPCC emissions factors ranges over 1 order of magnitude

Need studies other two sites with different soil types, cropping systems, mgmt practices.